Journal of Forestry Research (2008) 19(1):32–36
DOI: 10.1007/s11676-008-0005-8

RESEARCH PAPER

Effects of coastal afforestation on some soil properties in Lakshmipur coast of Bangladesh

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Abstract: Coastal zones comprising important intertidal tropical and subtropical ecosystems are characterized by high productivity, diversity and unique zonation of various plant and animal communities. The comparison of some selected physicochemical soil properties viz. texture, particle density, moisture content, pH, organic carbon and total nitrogen between planted site (Telir *char*) and barren site (Boyar *char*) has been investigated at surface (0-10 cm) and subsurface (10-45 cm) soil across three different land strips viz. inland, middle part and sea side in Lakshmipur coast of Bangladesh. Sand particles in the soil were lower in planted site than barren site. The reverse trend was found in case of both silt and clay percentage. Coastal afforestation had a significant effect on soil binding process since a common trend of increment in soil particle density was noticed. Maximum increment (20.43% to 23.30%) in soil moisture content was recorded in surface soil across the seaside while at subsurface soil both across the middle part (19.53% to 22.30%) and sea side (20.19% to 22.96%). Moreover, the highest reduction in soil pH was recorded at surface soil (7.27 to 6.60) across the sea side and subsurface soil (7.16 to 6.67) in inland due to the influence of coastal plantation. Across all the land strips and the soil depths studied, soil organic carbon was higher in planted site than in barren site with only exception at subsurface soil in the middle part (0.50% in both sites). Total soil nitrogen in the study area was increased at both depths due to forestation with the highest increment in the inland at both surface and subsurface soil.

Keywords: mangroves; plantation; physicochemical properties; soil depth

Introduction

Coastal ecosystems, the dominant intertidal community types of marine to fresh water ecotones along seas, oceans and estuaries (Chen et al. 1999), are critically evaluated for their simultaneous vulnerabilities and opportunities (ICZMP 2007). The coastal zone of Bangladesh, about 710 km long extending along the Bay of Bengal, lies between latitude 21–23°N and longitude 89–93°E comprising 19 districts viz. Bagerhat, Barguna, Barisal, Bhola, Chandpur, Chittagong, Cox's Bazar, Feni, Gopalganj, Jessore, Jhalokati, Khulna, Lakshmipur, Narail, Noakhali, Patuakhali, Pirojpur, Satkhira and Shariatpur including estuaries and off-shore islands (ICZMP 2007; Siddiqi 2001). The coastal region of Bangladesh is characterized by a vast network of rivers, an enormous discharge of river waters heavily laden with sediments, numerous islands in between the channels and rivers, a very shallow area along the coast and the Swatch of No Ground, a submarine canyon (Ali 2000). Sundarban, the unique natural mangrove ecosystem in the world, exists in this region (Siddiqi 2001).

Plantation of coastal areas with mangrove species in Bangladesh was initiated in 1960 emphasizing the mitigation of disastrous effects of cyclones and storm surges, production of timber for fuel wood and industrial use, conservation and stabilization of newly accreted lands and ultimate transfer of a large part of such lands to agriculture (Siddiqi 2001). Up to 2002–2003, a total of 148 792.25 ha of mangrove plantation has been established through different development projects (Shamsuddin et al. 2003). Major mangrove species planted on the newly accreted lands along the coastal belt, estuaries and river banks were *Sonneratia apetala, Avicennia officinalis, A. marina, A. alba, Amoora cucullata, Bruguiera gymnorrhiza, Excoecaria agallocha, Xylocarpus mekongensis, Ceriops decandra* and *Nypa fruticans* (Das et al. 1985).

The mangroves offer significant ecological services in coastal ecosystems. They contribute to the stabilization of the shoreline and prevention of shore erosion. Dense network of modified mangrove root systems traps the sediments. Litter production by the mangroves and subsequent decomposition processes reduces soil salinity and enhances the activities of heterotrophic microorganisms thus uplifting nutritive value of the soil (Rao et al. 2007).

Received: 2007-09-07; Accepted: 2007-11-05

The online version is available at http://www.springerlink.com
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Responsible editor: Zhu Hong

Coastal afforestation effects on soil properties like soil texture, color (Bandyopadhyay 1995), moisture content, water retention capacity (Khan et al. 1998; Jonston et al. 1995), pH (Pal et al. 1996; Hasan 2000; Cardona et al. 1998; Sukardjo 2007), salinity (Siddiqi et al. 1990; Cardona et al. 1998; Khan et al. 1998), organic matter (Eswaren et al. 1993; Machiwa et al. 1998), total nitrogen availability (Khan et al. 1998) were vivid. Besides, mangrove plantations have significant impacts on land mass increment (Siddiqi et al. 2001), land stabilization (Mc Conichie 1990) and rate of siltation (Imam 1984; Howlader 1999).

Afforestation activities along Lakshmipur coast of Bangladesh with mangrove species were started from 1967. Up to 2002–2003, about 57 433 ha of coastal lands were afforested under different governmental projects like Forest Resources Management Project (FRMP), Coastal Greenbelt Project (CGP), Char Development and Settlement Project (CDSP) and Forestry Sector Project (FSP). *Sonneratia apetala* was used as a pioneer species for afforestation of newly accreted land while partially stabilized and slightly raised lands were afforested with *Excoecaria agallocha* and *Avicennia officinalis* (Shaifullah 2006). Copious works (Boto et al. 1984; Gunasekaran et al. 1992; Cardona et al. 1998; Tam et al. 1998; Matthijs et al. 1999; Vilarrubia et al. 2000) on effects of coastal afforestation on soil properties in global perspectives have been performed so far. But no such study in coastal areas of Bangladesh except the Sundarban (Siddiqi 2001) to evaluate the alternation of soil physicochemical properties due to coastal afforestation has yet been carried out. The present study is, therefore, an attempt to assess the effects of coastal afforestation on some selected soil properties in Lakshmipur coast of Bangladesh.

Materials and methods

Selection of sampling sites

Soil samples for the study were collected from two purposively selected paired *char*(s), (a tract of land surrounded by the waters of an ocean, a sea, a lake, or a stream; usually any accretion in a river course or estuary), viz. Telir *char* and Boyar *char*, 100 m apart from each other, under Lakshmipur Coastal Forest Division during August 2006 (Siddiqi 2001). Mean monthly temperature of the study area varies between 19°C in winter and 29°C in summer while mean annual rainfall is recorded 4 000 mm over last ten years. Telir *char* was occupied with an even-aged monoculture plantation of seven years old *Sonneratia apetala* while Boyar *char* was completely barren. Each *char* was segmented into three land strips (each of 100-m width) from sea towards mainland viz. sea side, middle part and inland. Mean height and diameter of *Sonneratia apetala* on Telir *char* were respectively 14.13 m and 9.41 cm in inland, 11.05 m and 8.16 cm in middle part and 8.58 m and 5.46 cm in sea side. Two sample plots of 50 m×50 m were selected from each land strip and a total of 24 composite soil samples were collected from two different depths viz. 0–10 cm (surface soil) and 10–45 cm (subsurface soil). Seven soil samples from sea side by using a Core Sampler and three from both the middle part and inland by digging 0.91 m×0.91 m pits were collected from each sample plot at each depth and mixed thoroughly to form a composite soil sample. Each composite sample was replicated three times for each observation.

Sample preparation and analysis

In the laboratory, the collected moist composite soil samples were first sieved through a 10-mm-mesh sieve to remove gravel, small stones and coarse roots and then passed through a 2-mm-mesh sieve. The sieved samples were then dried at 25°C to determine soil texture (Huque et al. 2005), pH (using digital pH meter TOA, Japan), and moisture content (oven dry method by Huque et al. 2005) and oven dried at 105°C for 8 h to analyze organic carbon (loss of ignition method by Ball 1964), particle density (Huque et al. 2005) and total nitrogen (Micro- Kjeldahl digestion procedure). All the data were analyzed statistically by using the computer software package Microsoft Excel 2003. Unless otherwise stated each value of studied parameters is means of six replications.

Results and discussion

Soil texture

Sand particle content of soil was recorded lower in planted site (Telir *char*) than barren site (Boyar *char*) across all the land strips studied. The reverse trends were found in case of both silt and clay percentage (Table 1). This trend reveals that coastal plantation in the study area showed a significant role in reducing the sand percentage and increasing both silt and clay percentage and eventually improving soil texture. The highest reduction (71.24% to 51.67%) in sand particles at surface soil (depth at 0–10 cm) was found in inland while at subsurface soil (depth at 10–45 cm) it was (75.38% to 51.29%) in middle part. Silt particle increment was found maximum in middle part at both surface (21.00% to 34.20%) and subsurface (21.20% to 39.00%) soil. In case of clay, the increment was the highest in inland (3.16% to 10.65%) at surface soil and in middle part (3.42% to 9.71%) at subsurface soil.

Table 1. Comparison of soil textural characteristics between planted site and barren site at two depths across three land strips

Land strips	Soil depth (cm)	Sample sites	Textural characteristics (%)		
			Sand	Silt	Clay
Inland	0-10	Planted site	51.67	37.60	10.65
		Barren site	71.24	25.60	3.16
	10-45	Planted site	50.37	38.20	7.85
		Barren site	73.45	24.81	1.74
Middle part	0-10	Planted site	59.23	34.20	6.57
		Barren site	75.39	21.00	3.61
	10-45	Planted site	51.29	39.00	9.71
		Barren site	75.38	21.20	3.42
Sea side	0-10	Planted site	65.15	29.60	5.25
		Barren site	69.82	25.51	4.67
	10-45	Planted site	62.10	27.36	3.90
		Barren site	70.81	24.00	1.83

Sukardjo (2007), while studying the characteristics of mangrove soils of Java, Indonesia, recorded that the mangroves had a significant role in increasing clay and silt parentage and reducing sand percentage of coastal soils which supports the present findings.

Soil particle density

Coastal afforestation had an important role in soil binding since a common trend of increment in soil particle density was noticed across the three land strips at both depths (Table 2). At surface soil, the highest increment (0.77 g/cc to 1.00 g/cc) was recorded across the inland. Soil particle density increased maximum (0.83 g/cc to 0.93 g/cc) at subsurface soil across both middle part and sea side.

Watt et al. (2005) found significant impact of vegetation on soil particle density in their study on sustainability of plantation forests through identification of site quality indicators influencing productivity in New Zealand. They recorded higher soil particle density in forested land in comparison to that of degraded and barren land which is similar to the findings of coastal soils in present study.

Table 2. Comparison of soil particle density between planted site and barren site at two depths across three land strips

Land strips	Soil depth (cm)	Sample sites	Soil particle density (g/cc)
Inland	0-10	Planted site	1.00
		Barren site	0.77
	10-45	Planted site	0.87
		Barren site	0.83
Middle part	0-10	Planted site	0.90
		Barren site	0.80
	10-45	Planted site	0.93
		Barren site	0.83
Sea side	0-10	Planted site	0.97
		Barren site	0.87
	10-45	Planted site	0.93
		Barren site	0.83

Soil moisture content

Soil moisture content was increased due to forestation at both depths across the land strips studied (Table 3). Maximum increment (20.43% to 23.30%) in soil moisture content was recorded in surface soil across the seaside while at subsurface soil both across the middle part (19.53% to 22.30 %) and sea side (20.19% to 22.96%).

Jonston and Alongi (1995) found soil moisture content ranging from 32.57% to 62.94% in the coastal forest of Mekong delta, Vietnam which does not coincide with the finding (18.38% to 23.30%) of the present study since the sites under present study were slightly matured. Jonston and Alongi (1995) also analyzed that the soil moisture content was higher due to the presence of vegetation in the coastal area which is in agreement with the present finding.

Table 3. Comparison of soil moisture content between planted site and barren site at two depths across three land strips

Land strips	Soil depth (cm)	Sample sites	Soil moisture content (%)
Inland	0-10	Planted site	20.72
		Barren site	18.38
	10-45	Planted site	20.24
		Barren site	19.64
Middle part	0-10	Planted site	21.95
		Barren site	20.14
	10-45	Planted site	22.30
		Barren site	19.53
Sea side	0-10	Planted site	23.30
		Barren site	20.43
	10-45	Planted site	22.96
		Barren site	20.19

Soil pH

Coastal afforestation was found to have significant lowering effect on soil pH at both depths across the three land strips. The highest reduction in soil pH was recorded at surface soil (7.27 to 6.60) across the sea side and subsurface soil (7.16 to 6.67) in inland (Table 4).

Tam and Wong (1998), while studying the variations of soil nutrient and organic matter content in a subtropical mangrove ecosystem, recorded that pH changes along tidal gradients were directly affected by the degree of litter production and decomposition. He also reported that the narrower plant coverage and less litter production the more the alkaline pH. Similar result was also recorded by Lacerda et al. (1995) and Tam et al. (1993). This is probably due to the release of various organic acids through the hydrolysis of tannin in mangrove plants and breakdown of organic matter content in litter (Liao 1990; Steinke et al. 1993).

Table 4. Comparison of soil pH between planted site and barren site at two depths across three land strips

Land strips	Soil depth (cm)	Sample sites	Soil pH
Inland	0-10	Planted site	6.90
		Barren site	7.15
	10-45	Planted site	6.67
		Barren site	7.16
Middle part	0-10	Planted site	6.93
		Barren site	7.23
	10-45	Planted site	6.67
		Barren site	7.13
Sea side	0-10	Planted site	6.60
		Barren site	7.27
	10-45	Planted site	6.73
		Barren site	7.13

Soil organic carbon

Across all the land strips and the soil depths studied, soil organic carbon was higher in planted site than in barren site with only

exception at subsurface soil in the middle part (0.50% in both sites). The highest increment of soil organic carbon was observed at both surface (0.53% to 0.80%) and subsurface (0.12% to 0.32%) soil across inland due to coastal afforestation (Table 5).

Table 5. Comparison of soil organic carbon between planted site and barren site at two depths across three land strips

Land strips	Soil depth (cm)	Sample sites	Soil organic carbon (%)
Inland	0-10	Planted site	0.80
		Barren site	0.53
	10-45	Planted site	0.32
		Barren site	0.12
Middle part	0-10	Planted site	0.73
		Barren site	0.54
	10-45	Planted site	0.50
		Barren site	0.50
Sea side	0-10	Planted site	0.49
		Barren site	0.35
	10-45	Planted site	0.62
		Barren site	0.48

The range of soil organic carbon (0.12% to 0.80%) recorded in the present study coincides with those of Shenzhen, China (Tam et al. 1995) and Tanzania (Machiwa et al. 1998). Mangrove litter is one of the important sources of organic carbon accumulation in mangrove soils. Mangrove stems and leaf litters, after fall and decomposition, incorporate into the soil surface, while death of roots add organic matter to the soil at varying depths (Lacerda et al. 1995). Therefore the broader the mangrove vegetation, the higher the organic carbon would be incorporated into coastal soils (Tam et al. 1998).

Total soil nitrogen

Total soil nitrogen in the study area was increased at both depths due to forestation. The highest increment was observed at both surface (0.0017% to 0.0185%) and subsurface (0.0059% to 0.0233%) soil across inland (Table 6). Interestingly, a reduction in total soil nitrogen from 0.0806% to 0.0046% was recorded at surface soil in sea side due to coastal afforestation. This may be due to high denitrification rate in vegetated sediments at sea side in comparison to unvegetated sediments which is in agreement with Siddiqi (2001) who found 3.5 times higher rate of denitrification in vegetated sediments (46 $\mu M \cdot m^{-2} \cdot d^{-1}$) than in unvegetated ones (13 $\mu M \cdot m^{-2} \cdot d^{-1}$) in some mangrove plantations of Bangladesh.

The range of total nitrogen (0.0017% to 0.0806%) found at both sites during the present study is with the agreement of Lin and Lin (1985), Jagtap (1987), Tam et al. (1995) and Khan et al. (1998). Tam and Wong (1998), in their study, noticed that the trend of changes in total nitrogen concentrations in coastal soils depends on mangrove vegetation as nutrient variations were related to nutrient releases from litter decomposition which also supports the present findings. They reported decomposed litter as an important input to soil nutrient pools based on the negative relationships between pH and total nitrogen as well as very significant positive correlations between soil organic matters found.

Table 6. Comparison of total soil nitrogen between planted site and barren site at two depths across three land strips

Land strips	Soil depth (cm)	Sample sites	Total soil nitrogen (%)
Inland	0-10	Planted site	0.0185
		Barren site	0.0017
	10-45	Planted site	0.0233
		Barren site	0.0059
Middle part	0-10	Planted site	0.0111
		Barren site	0.0098
	10-45	Planted site	0.0170
		Barren site	0.0069
Sea side	0-10	Planted site	0.0046
		Barren site	0.0806
	10-45	Planted site	0.0118
		Barren site	0.0090

Conclusion

Soil particle density, moisture content, organic carbon and total nitrogen were increased and soil pH was decreased in the consequence of coastal afforestation at both surface and subsurface soil across inland, middle part and sea side in Lakshmipur coast of Bangladesh. While studying the soil texture at different depths it was revealed that the sand particles in coastal soil were decreased and both silt and clay contents were increased due to vegetation effect. On the whole, coastal afforestation in the study area was found to have distinct impact on improving the soil environment and thus satisfying the national coastal afforestation goals of stabilizing newly accreted coastal lands and ultimately transferring those lands to agriculture. In this regard, newly accreted lands have to be brought under plantation along with ensuring proper protection measures for the purpose of stabilizing the fragile coastal sediments as well as for accelerating further accretion.

References

Ali A. 2000. Vulnerability of Bangladesh coastal region to climate change with adaptation options. In: APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia-Pacific Region. Kobe, Japan – November, 14–16.

Ball DF. 1964. Loss on ignition as an estimate organic matter and organic carbon in non-calcareous soil. *Journal of Soil Science*, **15**: 84–92.

Bandyopadhyay AK. 1995. *Coastal soil and their management*. India: International book distributors, Rajpur Road, Dehradun, 135pp.

Boto KG, Wellington JT. 1984. Soil Characteristics and Nutrient Status in a Northern Australian Mangrove Forest. *Estuaries*, **7**(1):61–69.

Cardona P, Boetro L. 1998. Soil characteristics and vegetation structure in a heavily deteriorated mangrove forest in the Caribbean coast of Colombia. *Biotropica*, **30** (1): 24–34.

Chen R, Twilley RR. 1999. Patterns of mangrove forest structure and soil nutrient dynamics along the Shark River Estuary, Florida. *Estuaries*, **22** (4): 955−970.

Das S, Siddiqi NA. 1985. The mangrove and mangrove forests of Bangladesh. Mangrove Silvicultural Division. Bulletin No.2.UNDP/FAO/Project BGD/79/017. Bangladesh Forest Research Institute, 142 pp.

Eswaran HE, van der Berg, Reich P. 1993. Organic carbon in soils of the world. *Soil Science Society American Journal*, **57**: 192-194.

Gunasekaran S, Jayapaul A, Raju PM. 1992. Distribution of mangrove plants in relation to the chemical characteristics of the soil. Muthupet, Tamil. *Asian Environment*, **14** (3): 59-69.

Hasan MM. 2000. Soils and problem soils of Bangladesh. Observer Magazine, Dhaka. 5th May. 23 – 24pp.

Howlader NI.1999. *Mangrove research and development*. Forest Research Management Project Mid term Review Mission II. Bangladesh: Bangladesh Forest Department, 91pp.

Huque FMI, Didar-Ul-Alam M. 2005. *A handbook on analyses of soil, plant and water*. Bangladesh: Bangladesh-Australia Centre for Environmental Research (BACER-DU), 246pp.

Imam SA. 1984. Sedimentation, soil conductivity, plant life and their interaction. Paper presented at UNDP/UNESCO Training Seminar on Geology, Sedimentology, Erosion and Accretion in Mangrove Areas, SPARRSO, Dhaka. 20pp.

Integrated Coastal Zone Management Project (ICZMP). 2007. http://www.iczmpbangladesh.org/. Page last modified: 19 March 2006 and downloaded at 10.30 am. 23rd August, 2007.

Jagtap TG. 1987. Seasonal distribution of organic matter in mangrove environment of Goa. *Indian J Ma. Sci*, **16** (2): 103−106.

Johnston DJ, Alongi DM.1995. Comparative study of soil properties in Mekong delta and Cao Mao Hill forest, Vietnam. *Canopy international*, **25**(2): 6−7.

Khan ZH, Husain MS, Mazumder AR. 1998. Properties of soils from the offshore Islands of Bangladesh. *Bangladesh Journal of Forest Science*, **27** (2): 114−120.

Lacerda LD, Ittekkot V, Patchineelam SR. 1995. Biogeochemistry of mangrove soil organic matter: a comparison between Rhizophora and Avicennia soils in south-eastern Brazil. Estuar. *Coast Shelf Sc*, **40**: 713–720.

Liao JF. 1990. The chemical properties of the mangrove solonchak in the northeast part of Hainan Island. *Acta Scientiarum Naturalium Universititis Synysatseni* (Suppl.), **9**: 68−72.

Lin P, Lin GH. 1985. Accumulation and biological cycle of the element nitrogen and phosphorus in a mangrove (Kandelia candel) community at Jiulongjian Estuary, Fujian. *Acta Phytoecologica et Geobotanica Sinica*, **9**: 21−31. (in Chinese)

Machiwa JF, Olfasson E. 1998. Distribution and remineralization of organic carbon in sediments of a mangrove stand partly contaminated with sewage waste. *Ambio*, **27**(8): 740−744.

Matthijs S, Tack J, Speybroeck D van, Koedam N. 1999. Mangrove species zonation and soil redox state, sulphide concentration and salinity in Gazi Bay (Kenya), a preliminary study. *Mangrove & Salt Marshes*, **3**(4): 234−249.

McConchie D. 1990b. Draft report on progress towards minimizing damage cause to coastal plantations by changes in land stability. UNDP/FAO Project BGD/85/085, Dhaka. Working Paper No. 37. (Mimeographed). 86 pp.

Pal D, Dash AK, Gupta SK, Sahoo AK. 1996. Vegetation pattern and soil characteristics of some mangrove forest zones of the Sundarban, West Bengal. *Indian Agriculturist*, **40** (2): 71−78.

Rao PVS, Raju S. 2007. Ecological importance of mangrove trees – the example of Bruguiera gymnorrhiza (L.) Lamk. (Rhizophoraceae). http://www.envfor.nic.in/news/aprjun05/ecological_mang.htm. downloaded at 10.35 am. 23rd August, 2007.

Shaifullh KM. 2006. *Coastal afforestation effects on environment in Lakshmipur Coastal Area*. Bangladesh: Institute of Forestry and Environmental Sciences, University of Chittagong, Bangladesh, 52 pp.

Shamsuddin AKM, Mehdi SA. 2003. Concept note on expectations, experiences and priorities for afforestation and reforestation under the Clean Development Mechanism (CDM). Bangladesh Report. Regional Workshop on Forests and Climate Change: Preparing for Decisions on Land Use & Forestry at COP9. Manila, Philippines 16 – 17 October.

Siddiqi NA. 2001. *Mangrove forestry in Bangladesh*. Chittagong, Bangladesh: Institute of Forestry & Environmental Sciences, University of Chittagong, 201 pp.

Siddiqi NA, Baksha MW. 2001. *Mangrove Research and Development*. Chittagong: Bangladesh Forest Research Institute, pp 6−10.

Siddiqi NA, Khan MAS. 1990. Growth performance of mangrove trees along the coastal belt of Bangladesh. Mangrove Ecosystem Occasional papers. No. 8 UNDP/UNESCO/RAS/86/120.Thomson Press, Delhi, pp 5-14.

Steinke TD, Holland AJ, Singh Y. 1993. Leaching losses during decomposition of mangrove leaf litter. *South African Journal of Botany*, **59**: 21–25.

Sukardjo S. 2007. The mangrove ecosystem of the northern coast of west Java. http://www.unu.edu/unupress/unupbooks/80130e/80130E09.htm. Page downloaded at 11.00 am. 23rd August, 2007.

Tam NFY, Vrijmoed LLP, Li SH, Wong YS. 1993. The Chemical characteristics of soil and its association with standing litter biomass in a sub-tropical mangrove community in Hong Kong. In: B. Morton (Ed.), *The Marine Biology of the South China Sea*,. Hong Kong: Hong Kong University Press, pp521−541.

Tam NFY, Wong YS. 1998. Variations of soil nutrient and organic matter content in a subtropical mangrove ecosystem. *Water, Air, and Soil Pollution*, **103**: 245–261.

Vilarrubia TV, Geohidra CA. 2000. Zonation pattern of an isolated mangrove community at Playa Medina, Venezuela. *Wetlands Ecology & Management*, **8**(1): 9−17.

Watt MS, Coker G, Clinton PW, Davis MR, Parfitt R, Simcock R, Garrett L, Payn T, Richardson B, Dunningham A. 2005. Defining sustainability of plantation forests through identification of site quality indicators influencing productivity—A national view for New Zealand. *Forest Ecology and Management*, **216**: 51−63.